GOATS 2005
Integrated, Adaptive Autonomous Acoustic Sensing Systems

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LONG-TERM GOALS

To develop net-centric, autonomous underwater vehicle sensing concepts for littoral MCM and ASW, exploiting collaborative and environmentally adaptive, bi- and multi-static, passive and active sonar configurations for concurrent detection, classification and localization of proud and buried targets.

OBJECTIVES

The objective of the continuing GOATS interdisciplinary research program is to develop, implement and demonstrate real-time, onboard integrated acoustic sensing, signal processing and platform control algorithms for adaptive, collaborative, multiplatform REA, MCM, and ASW in unknown and unmapped littoral environments with uncertain navigation and communication infrastructure.

A principal GOATS objective the development of a nested, distributed command and control architecture that enables individual network nodes of clusters of nodes to complete the mission objectives, including target detection, classification, localization and tracking (DCLT), fully autonomously with no or limited communication with the network operators. The need for such a nested, autonomous communication, command and control architecture has become clear from the series of experiments carried out in the past under GOATS. Thus, the experiments, most recently MB'06, have shown that acoustic communication cannot be relied upon for more traditional,

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14. ABSTRACT

To develop net-centric, autonomous underwater vehicle sensing concepts for littoral MCM and ASW, exploiting collaborative and environmentally adaptive, bi- and multi-static, passive and active sonar configurations for concurrent detection, classification and localization of proud and buried targets.

15. SUBJECT TERMS

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centralized network control due to inherent, physics-driven limitations in regard to bandwidth, and equally important, in terms of its inherent latency and intermittency.

APPROACH

The GOATS (Generic Ocean Array Technology Sonar) research program is a highly interdisciplinary effort, involving experiments, theory and model development in advanced acoustics, signal processing, and robotics. The center-piece of the research effort has been a series of Joint Research Projects (JRP) with SACLANTCEN. The joint effort was initiated with the GOATS' 98 pilot experiment [1] and continued with the GOATS' 2000 and BP02/MASAI02 experiments. Currently the collaboration is being continued under two NURC JRPs – one on hybrid target scattering modeling, and one on Focused Acoustic Fields (FAF), which constituted part of the joint experiments in 2004-05. A new JRP on littoral surveillance has just been approved, beginning in 2007. In addition to the field experiments involving significant resources provided by NURC, GOATS uses modeling and simulation to explore the potential of autonomous underwater vehicle networks as platforms for new sonar concepts exploring the full 3-D acoustic environment of shallow water (SW) and very shallow water (VSW).

The fundamental approach of GOATS is the development of the concept of a network of AUVs as an array of *Virtual Sensors*, based on fully *integrated sensing, modeling and control*, reducing the inter-platform communication requirements to be consistent with the reality of shallow water acoustic communication in regard to low bit-rate, latency and intermittency. Thus, for example the past GOATS effort has demonstrated that platform motion information can be used for clutter control by providing geometric constrains to on-board detection algorithms, reducing the communication requirements to location, POD, and classification information. Conversely, on-board sensor fusion and processing can be fed back to the vehicle control system for autonomous, adaptive sampling – again with the potential for significantly enhanced POD/PFA performance.

In regards to applications to MCM, GOATS explores the use of bi-static and multi-static Synthetic Aperture created by the network, in combination with low frequency (1-10 kHz) wide-beam insonification to provide coverage, bottom penetration and location resolution for concurrent detection, localization and classification of proud and buried targets in SW and VSW. The signal processing effort is therefore centered around generalizing SAS processing to bi-static and multi-static configurations, including bi-static generalizations of auto-focusing and track-before-detect (TBD) algorithms. Another issue concerns the stability and coherence of surface and seabed multiples and their potential use in advanced low-frequency SAS concepts.

More recently, the GOATS effort has transitioned towards the development of similar, autonomous network concepts for passive littoral surveillance, e.g. the Undersea Persistent Surveillance (UPS) program, under which MIT is co-leading the PLUSNet partnership which is developing a network concept of operations based on clusters of AUV and gliders, connected via acoustic communication, and intermittent RF communication with the operators through periodically surfacing gliders. As in the past GOATS effort, MIT is utilizing the open-source MOOS control mission control software originally developed and funded under GOATS.

The development of GOATS concepts, including PLUSNet, is based heavily on simulation, incorporating and integrating high-fidelity acoustic modeling, platform dynamics and network communication and control. In regard to the environmental acoustic modeling, MIT continues to develop the OASES-3d modeling framework for target scattering and reverberation in shallow ocean

waveguides. As has been the case for the autonomous command and control, recent emphasis has been towards the simulation of passive DCLT by the PLUSnet network. As was previously the case for the MCM effort, the approach has been to develop a complete system simulation capability, where complex adaptive and collaborative sensing missions can be simulated using state-of-the-art, high-fidelity acoustic models for generating synthetic sensor signals in real time. As in the past, this has been achieved by linking the real-time MOOS simulator with the SEALAB acoustic simulation framework, which in 'real-time'generates element-level timeseries using Green's functions using legacy environmental acoustic models such as OASES, CSNAP, and RAM. This new unique simulation environment allows for full simulation of adaptive DCLT missions for the MIT/Bluefin Macrura AUV towing a vector sensor array, incorporating correlated and directional ambient noise, and signals generated by moving surface ships and targets

This report covers the acoustic modeling and analysis effort funded under GOATS by Code 321OA. A companion report describing the effort associated with the MOOS-IvP autonomy software architecture funded by Code 321OE.

WORK COMPLETED

3D Acoustic Propagation and Scattering in 2D environments.

A numerically efficient coupled-mode formulation for the propagation and scattering by cylindrical ocean features, such as seamounts and islands has been developed [7]. The new modeling framework has been validated by comparison to the canonical problem of propagation around a cylindrical island, as illustrated in Fig.1, a problem introduced in earlier, related work [8]. The cylindrical island is assumed to be perfectly rigid, the water depth is h=250 m. The source frequency is 60 Hz, and the source is placed at a range of 1000 m from the center of the island, at a depth of 83 m. The radius of the island is 200 m. The convergence analysis in terms of the number of azimuthal modes is illustrated in Fig.2, which depicts transmission loss at depth 83 m, along a radial at azimuthal angle π. As seen from Fig. 2, the number of azimuthal modes required in the model is much less than that in the previous work [8] to obtain convergent result. This is due to the fundamental superposition principle used in the new approach, making the number of required azimuthal modes independent of the range of the source [7]. This feature is even more important for realistic seamount problems, such as the one described below, problems which could not be handled at all on todays computers due to high number of azimuthal modes required. Transmission loss for the cylindrical island problem, computed in the horizontal plane at depth 83 m is shown in Fig.3, while Fig. 4 shows a polar plot of the scattered intensity vs azimuthal angle, both illustrating the superior convergence rate of the new approach.

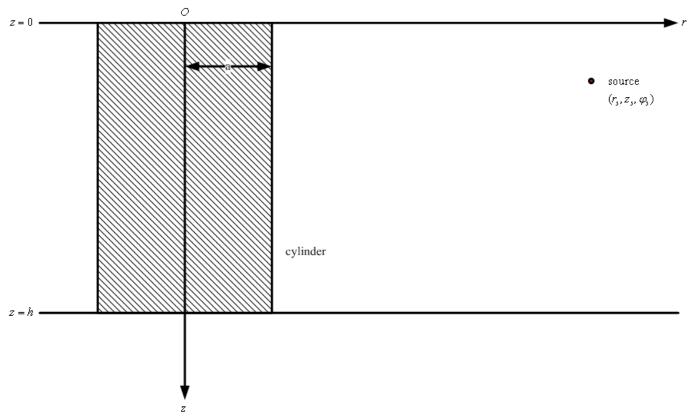


Fig.1 An ocean waveguide with a cylindrical island of radius 200 m, insonified by a point source at 100 m range..

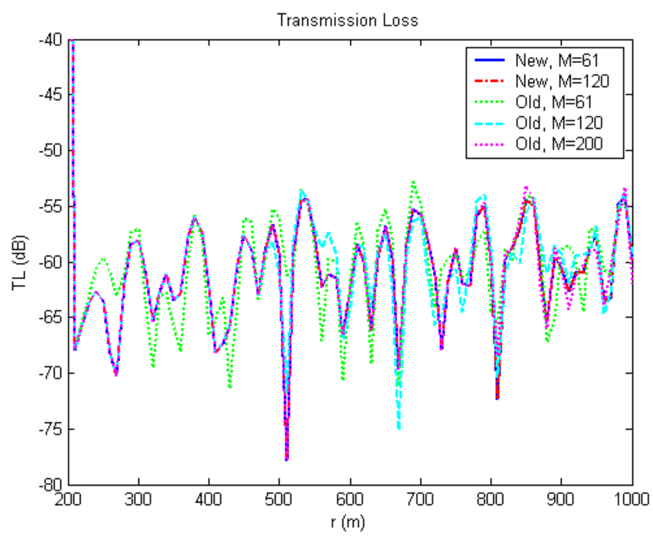


Fig.2 TL vs. range at $\varphi = \pi$ (range is from the axle of the cylindrical island). Our approach gives convergent result from 200 m to 1000 m with 61 azimuthal modes, while Athanassoulis and Propathopoulos's approach [7], required 200 azimuthal modes for convergence.

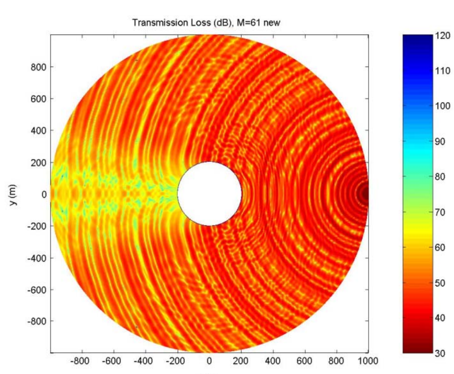


Fig.3 Transmission loss at depth h/3.

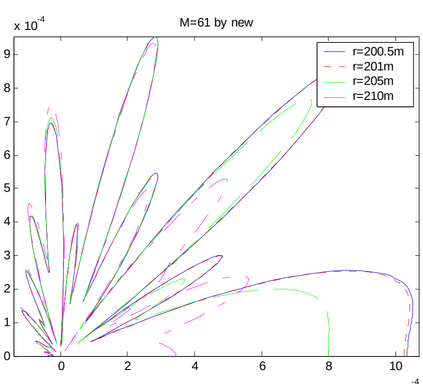
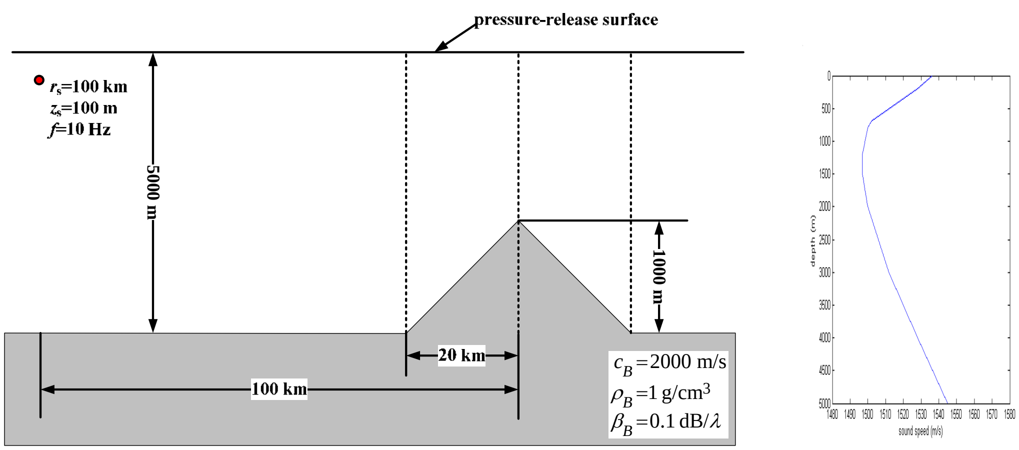


Fig.4 Azimuthal scattered intensity distribution.

RESULTS

3D Acoustic Scattering from a Conical Seamount

The new coupled-mode modeling framework for propagation around conical or cylindrical seamounts have been used to investigate the significance of the sound speed profile and the height of the seamount to the shadowing behind the seamount. A canonical seamount model shown in Fig. 5 is used for this study. The ocean waveguide consists of a inhomogeneous water column limited above by a pressure-release flat sea surface and below by a homogeneous fluid half space with a compressional speed of 2000 m/s, a density of 1 g/cm^3, and an attenuation of 0.1 dB/λ. The seamount is 100 km from the source, and has a height of 1000 m or 3800 m, and a radius of the base of 20 km, as well as the same acoustic properties as the bottom. The source depth is 100 m and the source frequency is 10 Hz. The schematic of this problem is shown in Fig.5(a). In addition, the sound speed profile in the external region with respect to the seamount is shown in Fig.5(b). Transmission loss in the horizontal plane at depth 300 m is depicted in Fig. 6, comparing the results obtained with a classical $N \times 2\mathrm{D}$ (vertical slices) model and the full 3D coupled mode model. The results illustrate the significance of the 3D effect for tall seamounts, reaching into the SOFAR channel (Fig. 6 c and d), while the effects are insignificant for smaller seamounts, as could be expected.



(a) (b)

Fig.5 A deep water seamount problem.
(a) The schematic of a deep water waveguide with a conical seamount and a penetrable bottom. (b) The sound speed profile in the water column.

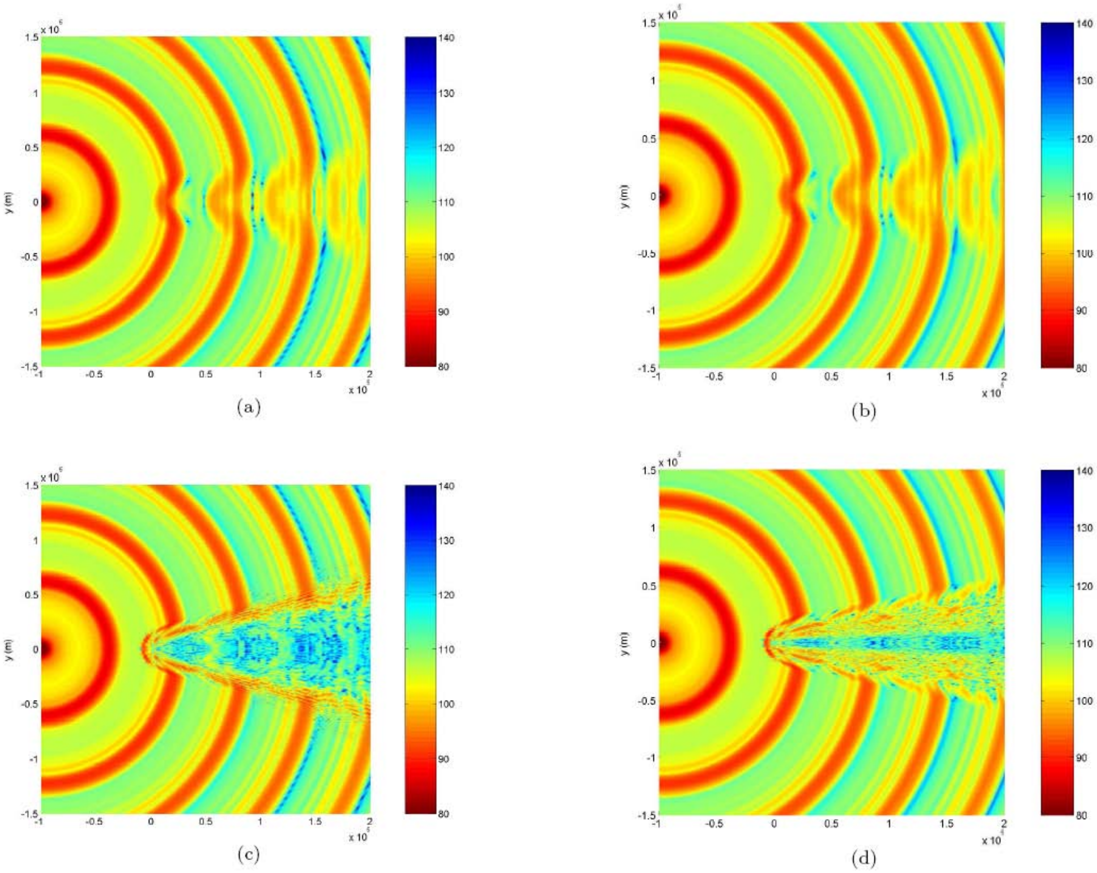


Fig.6 Transmission loss contours in the horizontal plane at depth 300 m. (a) Seamount height H =1000 m, Full 3D result, (b) H = 1000 m, $N \times 2\mathrm{D}$ result; (c) H = 3800 m, Full 3D result, (d) H = 3800 m, $N \times 2\mathrm{D}$ result.

IMPACT/APPLICATIONS

The long-term impact of this effort is the development of new sonar concepts for MCM and ASW, which take optimum advantage of the mobility, autonomy and adaptiveness of an autonomous, cooperating vehicle network. For example, bi- and multi-static, low-frequency sonar configurations are being explored for completely or partially proud or buried mines in shallow water, with the traditional high-resolution acoustic imaging being replaced by a 3-D acoustic field characterization as a combined detection and classification paradigm, exploring spatial and temporal characteristics which uniquely define the target and the reverberation environment. Similarly, platform mobility and collaboration is being explored for enhancing DCLT performance of littoral surveillance networks such as PLUSNet.

TRANSITIONS

The progress made in autonomous, multi-AUV, net-centric control, navigation, communication, and collaborative sensing is being transitioned into the ASAP-MURI and the new Undersea Persistent

Surveillance (UPS) PLUSNet efforts, both of which have which MIT as partners, with field demonstrations of autonomous adaptive sensing and control in Monterey Bay in FY06, and MINUS'07 (Newport,RI) and PN'07 (Dabob Bay, WA) in FY07. PI Schmidt is Co-lead PI on PLUSNet.

Further, the MOOS software architecture developed by P. Newman under GOATS funding is being transitioned to the new ONR UC@I program, where it is reqired to be use by all performers.

Finally, MOOS-IvP is being transitioned to handle the Mission Planning and Control of both moving and fixed assets in the NSF ORION Ocean Observatories. Thus MIT is partner in the UCSD led team charged with developing the Cyber Infrastructure for ORION, with responsibility for the MP&C.

The seismo-acoustic models developed by MIT are being maintained and dissiminated under the GOATS grant. The OASES and CSNAP environmental acoustic modeling codes are used extensively in the ONR sponsored r5esearch at MIT, and continue to be maintained, expanded and made available to the community. The latest addition is a 3D version of CSNAP, which efficiently provides wave-theory solutions for propagation and scattering around seamounts. OASES and CSNAP is continuously being exported or downloaded from the OASES web site, and used extensively by the community as a reference model for ocean seismo acoustics in general. (http://acoustics.mit.edu/arctic0/henrik/www/oases.html) Among the new transitions to applied Navy programs, the OASES and CSNAP framework is being used extensively by several contractors such including Lockheed-Martin, BBN, Northrop-Grumman, and SAIC., and Navy laboratories, including NUWC, NURC, CSS, and NRL.

RELATED PROJECTS

This effort has constituted part of the US component of the GOATS`2000 Joint Research Project (JRP) with the SACLANT Undersea Research Centre, and is currently collaborating with NURC under the Autonomous Sensing Networks Joint Research Projects (JRP). The MIT GOATS effort has been funded jointly by ONR codes 321OA (Livingston), 321OE (Swean,Curtin), and 321TS (Johnson/Loeffler/Commander).

The GOATS program developed out of the ONR Autonomous Ocean Sampling Network (AOSN) initiative completed in FY00, and is strongly related to the continuing AOSN effort. GOATS is also directly related to the Shallow Water Autonomous Mine Sensing Initiative (SWAMSI), initiated in FY04, and currently continuing, of which MIT is a partner.

The adaptive command and control architecture and acoustic modeling capabilities developed under GOATS are being applied in several other related programs MIT is partnering in, including the AREA (Adaptive Rapid Environmental Assesment) component of the now completed ONR "Capturing Uncertainty" DRI, aimed at mitigating the effect of sonar performance uncertainty associated with environmental uncertainty by adaptively deploying environmental assesment resources. The cooperative AUV behavior progress together with the AREA concept is being currently transitioned into the ASAP MURI and the Undersea Persistent Surveillance (UPS) program, with experimental demonstrations in Monterrey Bay in MB06.

The OASES modeling framework, which is being maintained, upgraded, and distributed to the community under this award, has been used intensively in all the related programs MIT is participating

in. The new 3D model of propagation over seamounts is being transitioned and applied to the analysis of the experimental results obtained at Kermit seamount under the NPAL program.

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Maria A. Parra-Orlandoni, “Target Tracking: Determining Optimal Towed Array Heading Onboard an Autonomous Underwater Vehicle in an Anisotropic Noise Field,” MS thesis, Massachusetts Institute of Technology, September 2007.

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HONORS/AWARDS/PRIZES

K. Cockrell, Best student paper/young presenter award in Acoustical Oceanography: “A proposed technique for source localization using an autonomous underwater vehicle,” 153rd Meeting Acoustical Society of America, Salt Lake City, Utah, June 2007.